HEX-AXIS HORIZONTAL MOVEMENT DYNAMIC SIMULATOR

FIELD OF THE INVENTION

The invention relates to a hex-axis horizontal movement dynamic simulator and more particularly to 6-degrees-of-freedom motion simulating equipment used in modular design.

BACKGROUND OF THE RELATED ART

An early structure of a 6-degrees-of-freedom motion simulating platform was proposed by the Englishman Steward and is customarily called the Stewart Platform. For a long time, there was no significant improvement in the design of the Stewart Platform, which employed a hydraulic or pneumatic system to achieve the effect of changing the length of an actuating rod by varying the stroke of a cylinder rod to enable 6-degrees-of-freedom spatial motion. Moreover, since the parts and components comprising the conventional Stewart Platform were not modular in design and oil and air leakage problems occasionally occurred with the hydraulic and pneumatic systems, the Stewart Platform was inconvenient and required substantial maintenance.

SUMMARY OF THE INVENTION

A goal of the present invention is to provide a solution to the above-described problems of the conventional Stewart Platform

by employing a modular design instead of the hydraulic or pneumatic system used by the conventional Stewart Platform.

Another goal of the present invention is to provide a hex-axis horizontal movement dynamic simulator that can simulate the motion of 6 degrees of freedom without employing a hydraulic or pneumatic system.

A further goal of the invention is to provide a hex-axis horizontal movement dynamic simulator having a modular structure that comprises three modular movement control units of the same structure. The modular movement control units are located at positions relative to each other forming three sides of an equilateral triangle and are pivoted to a load-carrying platform by a universal-joint yoke mechanism corresponding to each of the three movement control units.

A further goal of the invention is to provide a specific structure of a modular movement control unit that can precisely control the movement of the load-carrying platform and provide a motion simulation platform having 6 degrees of freedom.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a first embodiment of the hex-axis horizontal movement dynamic simulator of the invention that has three sets of movement control units of the same structure located

separately at the positions forming three sides of an equilateral triangle.

FIG. 2 illustrates the hex-axis horizontal movement dynamic simulator of FIG. 1 showing the variation of translation and angular motion of the load-carrying platform.

FIG. 3 is a schematic drawing of the invention shown in FIG. 2 as viewed from another direction.

FIG. 4 is a disassembly drawing showing the parts of the movement control unit illustrated in FIG. 1.

FIG. 5 illustrates a second embodiment of the hex-axis horizontal movement dynamic simulator having three sets of movement control units of the same structure located separately at the positions forming three sides of an equilateral triangle.

FIG. 6 is a disassembly drawing showing parts of the movement control unit illustrated in FIG. 5.

FIG. 7 illustrates a third type of embodiment of the hex-axis horizontal movement dynamic simulator having three sets of movement control units of the same structure located separately at the positions forming three sides of an equilateral triangle.

FIG. 8 is a disassembly drawing showing the parts of the movement control unit illustrated in FIG. 7.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1 and FIG. 2, a key point of the invention is that no hydraulic or pneumatic system is used in a hex-axis motion simulator 10. For each universal-joint yoke mechanism 27, one end of each of two fixed-length connecting rods 26 are pivoted to the universal-joint yoke mechanism 27 and the other ends of the connecting rods 26 are separately connected to a transmission-joint yoke mechanism 25. Further, each transmission-joint yoke mechanism 25 is pivoted to a sliding seat 24 and the rectilinear translation motion and position of each transmission-joint yoke mechanism 25 is controlled by controlling the rectilinear translation and position of the corresponding sliding seat 24 so as to generate a motion of 6 degrees of freedom that controls the spatial motion and position of the load-carrying platform.

Hex-axis horizontal movement dynamic simulator 10 comprises three movement control units 20, of the same structure, that are fixed on a foundation 50 at the locations relative to each other forming three sides of an equilateral triangle. Each of the three movement control units 20 is pivoted to the load carrying platform 60 by a universal-joint yoke mechanism 27. Thus the locations at which the three universal-joint yoke mechanisms 27 are pivoted to the load-carrying platform 60 form an equilateral triangle.

Each movement control unit 20 is symmetrically structured to comprise a universal-joint yoke mechanism 27, two connecting rods of fixed length 26, two transmission-joint yoke mechanisms 25, two sliding seats 24, two lead screws 23, two servo-driving mechanisms 22, and a rectilinear translation guide 21. Since universal-joint yoke mechanism 27 is pivotally connected to load-carrying platform 60, it can generate a motion of 1 degree of freedom relative to load-carrying platform 60. Since one end of each of the two connecting rods 26 is pivotally connected to the same universal-joint yoke mechanism 27, the connecting rod can generate a motion of 2 degrees of freedom.

Therefore, the end of the connecting rod pivoted to the universal-joint yoke mechanism 27 has 3 degrees of freedom for generating a spatial motion relative to the load-carrying platform. Further, the other ends of the two connecting rods are symmetrically pivoted to separate driving joint yoke mechanisms 25 that can generate a spatial motion of 2 degrees of freedom. Since the transmission-joint yoke mechanism 25 of each connecting rod 26 is pivoted to a sliding seat 24, the transmission-joint yoke mechanism 25 has 1 degree of freedom for generating a spatial motion relative to the sliding seat 24. Therefore, the end of the connecting rod 26 pivoted to the transmission-joint yoke mechanism 25 has 3 degrees of freedom relative to the sliding seat 24 for spatial motion.

Based on the above-mentioned arrangement, both ends of each connecting rod 26 of each movement control unit 20 have 3 degrees of freedom for generating a spatial motion. Since all connecting rods are fixed-length rigid bodies, when the sliding seat 24 is displaced rectilinearly, the transmission-joint yoke mechanism 25 on one end of the connecting rod 26 is restricted to rectilinear translation together with the sliding seat 24, which enables the connecting rod 26 to generate a spatial displacement of 6 degrees of freedom. Through the variation of spatial position of every connecting rod 26, the universal-joint yoke mechanism 27 on the other end of the connecting rod 26 will generate a relative spatial-displacement following the rectilinear displacement of the transmission-joint yoke mechanism 25.

Therefore, when the sliding seat 24 makes a rectilinear translation to another place together with the transmission joint yoke mechanism 25 to which it is pivoted, the spatial position of the connecting rod 26 on the transmission-joint yoke mechanism 25 associated with 6 degrees of freedom will vary. That is, the universal-joint yoke mechanism 27 on one end of each connecting rod 26 will change its spatial position relative to the transmission-joint yoke mechanism 25 and actuate the load-carrying platform 60 to vary its spatial position.

Each of FIGs. 1-3 corresponds to the rectilinear displacement of different sliding seats 24, which slide on different movement

control units 20 that are respectively located at the positions forming three sides of an equilateral triangle. The sliding seats 24 may have relative displacements for the load-carrying platform 60. Therefore, through the synchronous and precise control of the rectilinear movement of each sliding seat 24 of each movement control unit 20, such as may be provided by a computer system, the spatial movement of each universal-joint yoke mechanism 27 relative to the others can be precisely controlled to achieve a precise control of the motion of load-carrying platform 60 and to generate linear and angular displacement spatially.

The mechanism that enables each sliding seat 24 of each movement control unit 20 to generate a rectilinear motion comprises two lead screws 23, two servo-driving mechanisms 22 having servo-motors 221, a rectilinear translation guide 21 having two guide seats 212 and two straight sliding rails 211. Each sliding seat 24 has a female screw thread that engages with the lead screw 23. The servo-motor 221 of the servo-driving mechanism 22 is employed to drive the lead screw 23 to rotate, which enables the sliding seat 24 on one of the guide seats 212 of the rectilinear translation guide 21 to be guided by the straight sliding rail 211 and to generate rectilinear displacement. Therefore, the rectilinear movement of each sliding seat 24 can be precisely controlled by the precise control of the rotating speed and angular displacement of the servo-motor 221 of each

servo-driving mechanism 22, through which a precise control of the variation of linear and angular displacement of the load-carrying platform 60 can be achieved.

The first embodiment of the movement control unit is shown in FIGs. 1-4 and comprises a base seat 40, a universal joint yoke mechanism 27, two connecting rods of fixed length 26, two transmission-joint yoke mechanisms 25, two sliding seats 24, two lead screws 23, two servo-driving mechanisms 22, and a rectilinear translation guide 21. The base seat 40 is a longitudinal plate fastened to the foundation 50 by bolt. The rectilinear translation guide 21 has two linear sliding rails 211 parallel to each other and two identical guide seats 212. The two linear sliding rails 211 are installed on the surface of the base seat 40 along the longitudinal direction of the base seat and parallel to each other, and the bottom side of each guide seat 212 has two parallel guide slots that match the shape and gauge of the two straight sliding rails 211. Thus, each guide seat 212 can be installed on and match the two straight sliding rails 211 and slide on the two straight sliding rails along the guiding direction.

Each servo-driving mechanism 22 comprises a servo-motor 221 assembled with a driving pulley 222, a driving belt 223, a driven pulley 224 and a bearing plate 225 that drives a lead screw 23. The bearing plate 225 of each servo-driving mechanism 22 is

installed at a position near a different end of the base seat 40 so as to form a bracket for mounting the two lead screws 23 with bearings and to have the two lead screws 23 parallel to the two straight sliding rails 211. The driving pulley 222 is mounted on the driving shaft of the servo-motor 221, and the driven pulley 224 is mounted on the lead screw 23. The driving pulley 222 and the driven pulley 224 are connected by the driving belt 223.

The sliding seat 24 is rectangular shaped and fastened to the guide seat 212 of the rectilinear translation guide 21. On the sliding seat 24, two penetrating holes 241, 242 are prepared. Hole 241 has a female screw thread and engages with the lead screw 23. The other hole 242 is a passage for another lead screw 23 to pass through. Further, on the top surface of each sliding seat 24, is a mounting recess 243 for pivotally mounting the transmission joint yoke mechanism 25.

The transmission-joint yoke mechanism 25 comprises a U-shaped yoke 251 and a T-shaped pivot axis. The horizontal stub shaft formed on both sides of the T-shaped pivot axis is pivoted to the two vertical portions of the U-shaped yoke 251 by a bearing and nut that enable the perpendicular stub shaft of the T-shaped pivot axis to have 1 degree of freedom of rotational motion relative to the U-shaped yoke 251. On the bottom side of the U-shaped yoke 251, is a mounting shaft 253 that is pivotally mounted to the mounting recess 243 by a bearing and nut that provide the

transmission joint yoke mechanism 25 with 1 degree of freedom of rotational motion relative to the sliding seat 24. The perpendicular stub shaft of the T-shaped pivot axis 252 of each transmission-joint yoke mechanism 25 has 2 degrees of freedom of rotational motion relative to the sliding seat 24 to which it is mounted.

The universal-joint yoke mechanism 27 comprises an inverse U-shaped yoke 271, a cardan shaft 272, a neck-ring seat 274, and a cover plate 275. The left and right horizontal stub shafts formed on both sides of the cardan shaft 272 are pivoted to the two vertical portions of the inverse U-shaped yoke 271 by a bearing and nut that enable the perpendicular stub shaft formed on the front and rear side of the cardan shaft (272) to have 1 degree of freedom of rotational motion relative to the inverse U-shaped yoke 271. On the top side of the inverse U-shaped yoke 271, is a mounting shaft 273 that is pivoted to the neck-ring seat 274 by a bearing. A cover plate 275 is mounted on the upper side of the neck-ring seat 274, through which the whole assembly of the universal-joint yoke mechanism 27 is mounted on the load-carrying platform 60. Thus, the inverse U-shaped yoke 271 has 1 degree of freedom of rotational motion relative to the neck-ring seat 274 or the cover plate 275. The perpendicular stub shaft on the front and rear side of the cardan shaft 272 of the inverse U-shaped yoke

271 has 2 degrees of freedom of rotational motion relative to the neck-ring seat 274 or cover-plate 275.

Every connecting rod 26 has a fixed length. On both ends of the connecting rod 26, are pivoting holes through which the front end of the connecting rod is pivotally connected to the front perpendicular stub shaft or rear perpendicular stub shaft of the cardan shaft 272 of the universal-joint 27. Thus, the pivoting hole on the front end of the connecting rod 26 has 1 degree of freedom of rotational motion relative to the perpendicular stub shaft of the cardan shaft 272. The pivoting hole on the front end of every connecting rod 26 has 3 degrees of freedom of rotational motion relative to the neck-ring seat 274 or cover plate 275. The pivoting hole on the rear end of every connecting rod 26 is pivotally connected to the perpendicular stub shaft of the T-shaped pivot axis 252 by a bearing and nut that provide the pivoting hole on the rear end of every connecting rod 26 with 1 degree of freedom of rotational motion relative to the perpendicular stub shaft of the T-shaped pivot axis 252. The pivoting hole on the rear end of every connecting rod 26 has 3 degrees of freedom of rotational motion relative to the sliding seat 24.

Since each end of the connecting rod 26 has 3 degrees of freedom of rotational motion, the whole connecting rod 26 has 6 degrees of freedom for generating a spatial motion. The

above-mentioned mechanism, as verified by the equation of mobility in Spatial Mechanism, generates a spatial motion of 6 degrees of freedom, according to Gruebler's formula for a spatial mechanism:

$$F = 6(L - j - 1) + \sum_{i=1}^{j} f_i$$

$$L = 32, j = 36, \sum_{i=1}^{j} f_i = 36; F = 6$$

Where

F: Number of degrees of freedom of the whole mechanism

L: Total number of members in the mechanism

J: Total number of joints in the mechanism

f_i: The number of degree of freedom of the i^{th} joint.

Therefore, the relative rotating angle and rotating speed of the servo-motor 221 of the servo-driving mechanism 22 of each movement control unit 20, based on the required data or condition of the relative motion of the load-carrying platform 60 in space and by applying the precise calculation and control of the computer system (not shown in drawings), can be synchronously controlled. The sliding seat 24 and transmission-joint yoke mechanism 25 on each of the three movement control units can synchronously generate different rectilinear movements to drive the connecting rods 26 to generate relative spatial-displacements

and control the relative spatial-movement of each universal-joint yoke mechanism 27, thus enabling the load-carrying platform 60 to vary its posture and angular position so as to simulate the state of a carrier (such as vehicle, ship, airplane and roller coaster etc.) making a spatial motion of 6 degrees of freedom.

In the following, is another embodiment of the movement control unit 20 that has the same mechanical structure and the same effect as that of the first embodiment of the control unit 20. This second embodiment applies the same technical and actuating principle to enable the load-carrying platform 60 to simulate a spatial motion of 6 degrees of freedom. The construction members and the inter-actuating relationship can be obtained by reference to the detailed description of the first embodiment mentioned above, which shall not be repeated here. The following description describes the second embodiment of the movement control unit 20.

The second embodiment of the movement control unit 20 is shown in FIGs. 5 and 6 and comprises a machine bed 41, one universal-joint yoke mechanism 27, two fixed-length connecting rods, two transmission-joint yoke mechanisms 25, two sliding seats 24, two lead screws 23, two servo-driving mechanisms 22, and a rectilinear translation guide 21. The components of the universal-joint yoke mechanism 27, the connecting rod 26, the transmission-joint yoke mechanism 25, the lead screw 23, the

servo-driving mechanism 22, and the rectilinear translation guide 21 are the same as those in the first embodiment of the invention.

But, the machine bed 41 of the second embodiment of the invention is a rectangular stand made of a metal plate having an inverse U-shaped cross-section that is fastened on the foundation 50. A cover plate 411 is mounted on both the left and right ends of the machine bed 41 with holes and an opening prepared at appropriate positions. The servo-motor 221 of the servo-driving mechanism 22 is installed inside the machine bed 41. The driving shaft of the servo-motor 221 extends outside the machine bed 41. Through the opening of the cover plate 411 of the machine bed 41, a driving pulley 222 is mounted and fastened on the driving shaft of the driving-servo motor 221. Two support plates 227 of the servo-driving mechanism 22 are installed at places closed to both ends of the machine bed 41 to form the support for pivotally mounting the two lead screws 23 by bearings in a position parallel to the two straight sliding rails 211 of the rectilinear translation guide 21. The driven pulley 224 is mounted and fastened on the lead screw 23 with a transmission belt installed on and passing through the driving pulley 222 and driven pulley 224. Therefore, the driving power of the servo-motor 221 is transmitted to the lead screw 23 through the driving pulley 222, the transmission belt 223, and the driven pulley 224.

The sliding seat 24 employed in the second embodiment of the invention comprises a sliding block 244 and a neck ring seat 246. The sliding block 244 is fastened on the guide seat 212 of the rectilinear translation guide mechanism 21. On the sliding block 244, two holes are provided, one of which has a female screw thread and engages with a lead screw 23. The other hole serves as the passage for another lead screw to pass through. The neck-ring seat 246 is fastened on the top side of the sliding block 244 or a fastening plate 245 is installed on the top side of the sliding block 244, first, and then the neck-ring 246 is fastened on the fastening plate 245. The mounting shaft 253 of the U-shaped yoke 251 of the transmission-joint yoke mechanism 25 is pivoted to the circular access on the tope side of the neck-ring seat 246 by a bearing and related parts.

The sliding seat 24 employed in the second embodiment and the first embodiment can be exchanged and used in either of the two embodiments or in other embodiments of the invention.

The third embodiment of the movement control unit 20 is shown in FIGs. 7 and 8 and comprises a base seat 40, a universal-joint yoke mechanism 29, two fixed-length connecting rods 26, two sliding yoke mechanisms 28, two leading screws 23, two servo-driving mechanisms 22, and a rectilinear translation guide 21. The connecting rod 26, lead screw 23, servo-driving mechanism 22, and rectilinear translation guide 21 are the same as those

employed in the first embodiment. The structure of the universal-joint yoke mechanism 29 is similar to the sliding yoke mechanism 28.

The universal-joint yoke mechanism 29 of the third embodiment comprises an inverse U-shaped yoke assembly 291, a pivoting plate 293, a pivoting shaft 295, two fixing blocks 296, an L-shaped yoke plate 297, a fastening yoke plate 298, and two cover plates 299. The L-shaped yoke plate is formed by a horizontal portion and a vertical portion. The horizontal portion is fastened on the load-carrying platform 60. A vertical portion hole is provided for mounting a shaft. The fastening yoke plate 298 is a plate-shaped member with appropriate thickness having an appearance symmetric to that of the vertical portion of the L-shaped yoke plate 297. A shaft mounting hole is also provided on the fastening yoke plate 298, which is to be assembled with the L-shaped yoke plate 297 to form a yoke assembly. The pivoting plate 293 is rectangular shape with a pivoting access in its center position and horizontal stub shafts 294 extended symmetrically from both sides opposite to each other that pivotally mount in the hole on the L-shaped yoke plate 297 and the fastening yoke plate 298 by bearings and related parts. The two cover plates are fastened on one side of the vertical portion of the L-shaped yoke plate 297 and the fastening yoke plate 298 to fix the whole assembly and provide the pivoting plate 293 with 1 degree of

freedom of rotational motion relative to the L-shaped yoke plate 297 and the fastening yoke plate 298. The yoke assembly 291 has a mounting shaft 292 extended upwardly from its top side and is mounted in the pivoting access in the center position of the pivoting plate 293 by a bearing, and a cover is fastened on the mounting surface of the pivoting plate to fix the assembly. Therefore, the yoke assembly has 1 degree of freedom of rotational motion relative to the pivoting plate 293 and has 2 degrees of freedom of motion relative to the L-shaped yoke plate 297 and the fastening yoke plate 298. The bottom side of the two flanks of the yoke assembly 291 has a semicircular recess, and the fixing block 296 also has a corresponding semicircular recess on the top side. A shaft 295 is pivotally installed by fixing the two fixing blocks on the bottom side of the two flanks of the yoke assembly 291, and both ends of the pivoting shaft 295 can be pivotally connected to the connecting rod 26 so as to provide the pivot hole on the front end of each connecting rod with 1 degree of freedom of rotational motion relative to the yoke assembly 291 and 3 degrees of freedom of rotational motion relative to the L-shaped yoke plate 297 and the fastening yoke plate 298.

The sliding yoke mechanism 28 employed in the third embodiment comprises a U-shaped yoke assembly 281, a pivoting plate 283, a shaft 285, two fixing blocks 286, an L-shaped sliding yoke plate 287, a sliding fastening plate 288, and two cover

plates 289. The L-shaped sliding yoke plate 287 has a horizontal portion and a vertical portion and is fastened on the guide seat 212 of the rectilinear translation guide 21 through its horizontal portion. The L-shaped sliding yoke plate 287 has two penetrating holes, one of which has a female screw thread and engages with the lead screw 23. The other hole serves as a passage for another lead screw 23 to pass through. In addition, the vertical portion of the L-shaped sliding yoke plate 287 has a pivoting hole. The sliding fastening plate 288 is a plate-shaped member of appropriate thickness and has an appearance symmetric to that of the vertical portion of the L-shaped sliding yoke plate. Two penetrating holes and a pivoting hole are provided on the sliding fastening plate 288. The two penetrating holes are for the two lead screws 23 to pass through. A yoke assembly is formed by assembling the sliding fastening plate 288 and the L-shaped sliding yoke plate 287. The pivoting plate 283 is rectangular shaped with a pivoting access in a center position and horizontal stub shafts 284 extended symmetrically from both sides opposite to each other that pivotally mount in the hole on the L-shaped sliding yoke plate 287 and the sliding fastening yoke plate 288 by a bearing and related parts. Two cover plates are fastened on one side of the vertical portion of the L-shaped sliding yoke plate 287 and the sliding fastening plate 288 to fix the whole assembly so that the pivoting plate 283 has 1 degree of freedom of

rotational motion relative to the L-shaped sliding yoke plate 287 and the sliding fastening plate 288. The yoke assembly 281 has a mounting shaft 282 extended downwardly from its bottom side that is pivotally mounted in the pivoting access in the center position of the pivoting plate 283 by a bearing and related parts. A cover is fastened on the pivoting plate 283 to fix the assembly. Thus, the U-shaped yoke assembly 281 has 1 degree of freedom of rotational motion relative to the pivoting plate 283 and has 2 degrees of freedom of rotational motion relative to the L-shaped sliding yoke plate 287 and the sliding fastening plate 288. The top side of the two vertical portions of the U-shaped yoke assembly has a semicircular recess, and a corresponding semicircular recess is provided on the fixing block 286 on the bottom side. A shaft 285 is pivotally installed by fixing the two fixing blocks 286 on the top side of the U-shaped yoke assembly, and both ends of the pivoting shaft 285 can be pivotally connected to the connecting rod 26 so as to provide the pivot hole on the rear end of the connecting rod 26 with 1 degree of freedom of rotational motion relative to the U-shaped yoke assembly 281 and 3 degrees of freedom of rotational motion relative to the L-shaped sliding yoke plate 287 and the sliding fastening plate 288. Since both ends of the connecting rod 26 have 3 degrees of freedom of rotational motion, each connecting rod 26 has 6 degrees of freedom of rotational motion in space.